Appendix A

An alternative analysis of Delta Action 8 Chinook salmon studies: A note for EWA Science Panel Review

Ken B. Newman
USFWS, Stockton FWO

An alternative analysis of Delta Action 8 Chinook Salmon Studies:
A Note for EWA Science Review Panel

Ken B. Newman, USFWS, Stockton FWO
November 3, 2006

1 Introduction

The Delta Action 8 (DA 8) Chinook salmon studies, which have been carried out annually since 1992, aim to quantify the possible relationship between water exports from the CVP and SWP facilities and juvenile Chinook salmon survival. Experimental protocol involves

- CWT'ing and ad-fin clipping hatchery reared juvenile Chinook salmon (fall run for 1992-1994 and late fall run for 1994-present);
- making paired releases of these fish at Georgiana Slough and at Ryde;
- recovering some of these fish by a midwater trawl at Chipps Island and in ocean fisheries.

Historical analyses (e.g., Brandes and McLain (2001)) have involved (1) calculating Georgiana Slough and Ryde survival indices based on Chipps Island recoveries or ocean fisheries recoveries, separately, (2) dividing the indices to get a relative survival index, and (3) fitting linear regressions of the relative survival index against export levels.

Such analyses have a number of limitations.

1. The Chipps Island survival indices are the observed recovery rate (number of recoveries divided by number released) scaled by a measure of gear efficiency. The measure of gear efficiency is based on the relative area swept by the trawl and the number of hours of trawling relative to an estimate of the time that fish are passing Chipps Island. The estimate of fish passage period, however, begins with the first recovery and ends with the last recovery and is likely biased low since some fish have potentially passed without capture before the date of first recovery and some have potentially passed without capture after the date of last recovery. If fish passage period is underestimated, then gear efficiency is overestimated and subsequently survival indices are overestimates of survival *probabilities*. Survival index values greater than 1.0 have been reported.
2. Recoveries at Chipps Island and in the ocean fisheries are by and large analyzed separately. Thus correlations between the recoveries from the same releases are ignored (a minor effect) and gains in precision by using the recoveries in combination are lost (more importantly).

3. The sampling variation in the survival indices, and relatedly the ratio of indices, is not accounted for in the regression model. In other words release numbers and capture probabilities vary between release pairings, and precision of the ratios varies and should be recognized in the regression analysis.

4. The ratio of survival probabilities likely varies between years (and potentially between release pairings made in the same year) as water conditions and fish condition vary. This between year variation is ignored in the analyses.

5. The analysis is a two-stage procedure, estimate survival ratios using observed data and then regress the estimated ratios against export levels. Integrated procedures that directly model observed data as a function of exports will generally be more statistically efficient, i.e., have smaller standard errors.

The alternative analysis described in this note addresses each of these limitations by using a hierarchical probability model for the joint distribution of recoveries at Chipps Island and in the ocean fisheries. Largely for pragmatic reasons, the model is fit using Bayesian methods, in contrast to classic statistical methods (e.g., maximum likelihood). The output from Bayesian methods consists of posterior probability distributions for the unknown parameters given the data and prior distributions for the parameters.

2 Methods

Hierarchical models, also known as a multi-level models, have two or more layers of probability models. In the case of the DA 8 studies, the bottom level consists of two trinomial distributions, one for Georgiana Slough releases and one for Ryde releases, for the Chipps Island and the ocean fishery recoveries. These trinomial distributions are conditional on the survival and capture probabilities specific to each release pairing. The second level of the hierarchical model then is a model for these probabilities, i.e., a model describing the between year variation in these probabilities. Instead of modeling the probabilities on their original scale, i.e., between 0 and 1, logistic transformations of these probabilities, log(p/(1-p)), are modeled using normal distributions. The survival ratio (on a logit scale) of Georgiana Slough to Ryde releases is modeled explicitly as a function of exports. For a Bayesian analysis, a third level exists: probability distributions, known as prior distributions, are specified for the constant, but unknown parameters of the second level.

Expressed more concisely in mathematical terms, the hierarchical model is as follows.
Level 1:

$$y_{GS\to CI}, y_{GS\to Oc} \sim \text{Trinomial}\left(R_{GS}, \theta r_{Ry\to CI}, r_{Ry\to Oc}\right) \quad (1)$$

$$y_{Ry\to CI}, y_{Ry\to Oc} \sim \text{Trinomial}\left(R_{Ry}, r_{Ry\to CI}, r_{Ry\to Oc}\right), \quad (2)$$

where the y's are the recoveries at Chipps Island (CI) or in the ocean fisheries (Oc) from the Georgiana Slough (GS) and Ryde (Ry) releases. The parameters r are the recovery probabilities for Ryde releases at each location and are combinations of survival and capture probabilities and the parameter θ is the ratio of the Georgiana Slough survival probability to the Ryde survival probability.

Level 2:

$$logit(\theta) \sim \text{Normal}\left(\beta_0 + \beta_1 Exports, \sigma_\theta^2\right) \tag{3}$$

$$logit(r_{Ry\to CI}) \sim \text{Normal}\left(\mu_{r_{Ry\to CI}}, \sigma^2_{r_{Ry\to CI}}\right) \tag{4}$$

$$logit(r_{Ry\to Oc}) \sim \text{Normal}\left(\mu_{r_{Ry\to Oc}}, \sigma^2_{r_{Ry\to Oc}}\right) \tag{5}$$

Level 3:

$$\beta_0 \sim \text{Normal}\left(0, 1.0E-6\right) \tag{6}$$

$$\beta_1 \sim \text{Normal}\left(0, 1.0E-6\right) \tag{7}$$

$$\mu_{Ry\to CI} \sim \text{Normal}\left(-6, 1.0E-6\right) \tag{8}$$

$$\mu_{Ry\to Oc} \sim \text{Normal}\left(-4, 1.0E-6\right) \tag{9}$$

$$\sigma_\theta^{-2} \sim \text{Gamma}\left(0.001, 0.001\right) \tag{10}$$

$$\sigma^{-2}_{r_{Ry\to CI}} \sim \text{Gamma}\left(0.001, 0.001\right) \tag{11}$$

$$\sigma^{-2}_{r_{Ry\to Oc}} \sim \text{Gamma}\left(0.001, 0.001\right) \tag{12}$$

The software program `WinBUGS` (Spiegelhalter, Thomas, and Best 2003) was used to generate samples from the posterior distributions using the late fall run Chinook salmon data alone.

3 Results

WinBUGS was run for 200,000 iterations with the first 50,000 values discarded (so-called "burn-in" period) and the posterior means, and standard deviations, for each pair-specific θ, the ratio of Georgiana Slough to Ryde survival probabilities are shown in Table 1. Note that these estimates are implicitly functions of the exports. For the sake of comparison, the classical statistical estimates, maximum likelihood estimates (mle), of θ and standard errors (calculated using the delta method) are also shown in the table. The classical estimates were not modeled as a function of exports and are simply the ratio of the recovery rates, and thus are not constrained to lie between 0 and 1. Despite these underlying differences in estimation procedures, the posterior means and mle's are quite similar, as are the posterior standard deviations and standard errors. This is evidence that the data dominate the effect of the prior distributions.

The last column of Table 1 shows the estimates of the survival ratios using the method of Brandes and McLean (2001) with the Chipps Island recoveries. While there are several release pairings with values similar to θ (a 1995 pairing, a 1999 pairing, 2000, 2004, and 2005), there are several, sometimes large differences as well (e.g., 1994 and a 1995 pairing).

The relationship between exports and the survival ratio, θ, is a function of the slope coefficient β_1 in Equation 3. If β_1=0 that indicates no relationship between θ and exports, while $\beta_1 < 0$ indicates a negative relationship, as exports increase, the Georgiana Slough survival probability relative to the Ryde survival probability decreases. Summary statistics from the posterior distribution for β_1 (and some other parameters) are shown in Table 2. From a hypothesis testing perspective, the null hypothesis is that there is no export effect, while the alternative hypothesis is that the export effect is negative, thus interest is just in the probability of β_1 being less than zero. There is over a 95% probability that θ is negative, thus some evidence for a negative association between θ and exports. A graphical display of the potential relationship between θ and exports is shown in Figure 1 where the mle's of θ (and standard errors) are plotted against exports. Included is a nonparametric regression and quadratic regression line (also shown are the fall run results). While this graph is a non-Bayesian, non-hierachical, and two-stage analysis, the gist of the results is consistent with the Bayesian, hierarchical, and integrated analysis, again suggesting an apparent negative association between exports and θ.

References

Brandes, P.L., and McLain, J.S., (2001), "Juvenile Chinook Salmon Abundance, Distribution, and Survival in the Sacramento-San Joaquin Estuary" in R. Brown ed. *Contributions to the Biology of Central Valley Salmonids*, Fish Bulletion 179, Vol 2, 39–136.

Spiegelhalter, D. Thomas, A., and Best, N. (2003), *WinBugs, Version 1.4. User Manual*, MRC, Cambridge, and Imperial College of Science, Technology, and Medicine, London.
(available at `http://www.mrc-bsu.cam.ac.uk/bugs`).

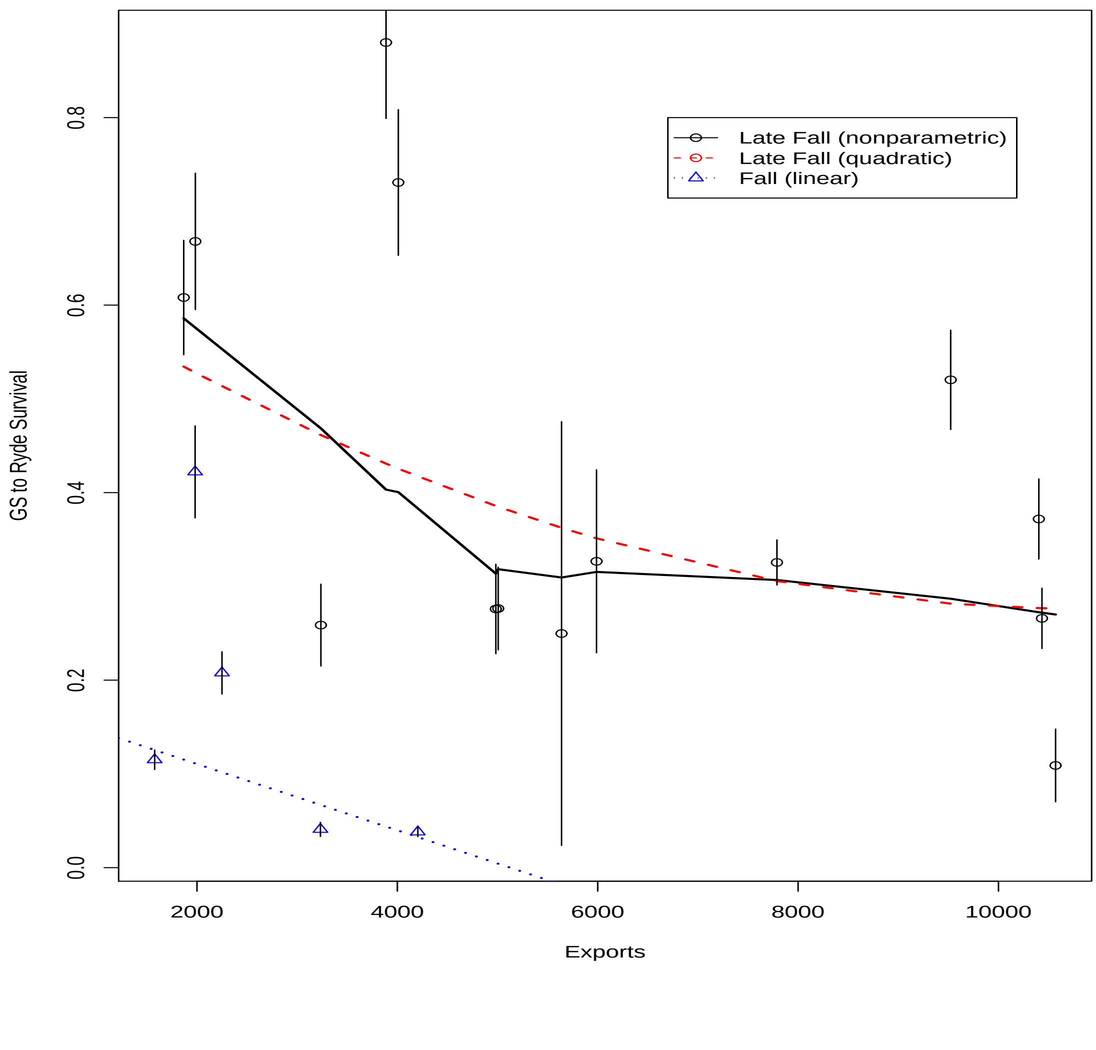
Table 1: Posterior distribution for ratio of the Georgiana Slough survival probability to the Ryde survival probability for late fall run Chinook salmon studies. Classical MLE (maximum likelihood estimate) and standard errors (using the delta method) are the non-Bayesian results. The 2005 results are based on Chipps Island recoveries alone. The last column with the ratio of survival indices is based upon the Chipps Island recoveries alone (Pat Brandes, personal communication).

	Posterior		Classical		Ratio of
Year	Mean	Std Dev	MLE	Std Error	Survival Indices
1994	0.27	0.033	0.27	0.032	0.14
1995	0.35	0.095	0.33	0.098	0.27
1995	0.37	0.042	0.37	0.043	0.16
1996	0.52	0.052	0.52	0.053	0.26
1998	0.13	0.041	0.11	0.039	0.05
1998	0.84	0.062	0.88	0.081	0.28
1999	0.62	0.061	0.61	0.061	0.24
1999	0.67	0.070	0.67	0.073	0.72
1999	0.27	0.045	0.26	0.044	0.16
2000	0.72	0.071	0.73	0.078	0.67
2000	0.33	0.025	0.33	0.024	0.31
2003	0.29	0.045	0.28	0.044	0.04
2004	0.28	0.048	0.28	0.048	0.28
2005	0.35	0.240	0.25	0.226	0.32

Table 2: Posterior distribution statistics for θ in the hierarchical model for DA 8 studies.

Parameter	Mean	0.025	0.05	0.50	0.95	0.975
β_1	-0.555	-1.177	-1.057	-0.548	-0.070	0.037

Figure 1: Estimated survival ratios (non-hierarchical model) for DA-8 studies plotted against export levels. Weighted regressions were used for all three models fit, with the weights being the inverse of the standard errors squared. The nonparametric regression of the late fall data used the supersmoother function in `R`.



Appendix B

Estimating Survival and Migration of Coded-Wire and Ultrasonic Tagged late-fall Chinook Smolts during their Passage through the Delta of the Sacramento –San Joaquin Watershed

Patricia Brandes
USFWS, Stockton FWO

Appendix B:

Estimating Survival and Migration of Coded-Wire and Ultrasonic Tagged late-fall Chinook Smolts during their Passage through the Delta of the Sacramento –San Joaquin Watershed

Pat Brandes, 11/8/06

Survival in the Delta for coded wire tagged Coleman National Fish Hatchery (CNFH) late-fall juveniles released into Georgiana Slough is lower than for those released at Ryde (Brandes and McLain, 2001). In addition, the relative interior Delta survival (the Georgiana Slough group relative to the Ryde group) is correlated to average Central Valley Project (CVP) and State Water Project (SWP) exports (Brandes et al, 2005). As exports increase, relative interior Delta survival decreases. To help understand how lower, interior Delta, survival may affect survival of juvenile salmon migrating through the Delta from Sacramento, this project has been planned. The proposed experiment will release two pairs of late-fall juvenile Chinook salmon tagged with coded wire (CWT) and VEMCO ultrasonic tags at Sacramento to measure survival through the Delta with the Delta cross channel (DCC) gates open and closed and compare results between the two methodologies. In addition, the ultrasonically tagged fish will be detected as they move downstream by VEMCO receivers placed throughout the Delta as part of a larger experiment conducted by our collaborators (UCD and NOAA). This tracking data will tell us how many juvenile salmon released at Sacramento enter Steamboat and Sutter Sloughs, and the interior Delta (via Georgiana Slough and the DCC) under the two DCC gate conditions. The importance of the lower relative survival in the interior Delta and its relationship to exports can be better assessed by understanding how many juveniles enter the interior Delta relative to the number taking other migration pathways. The release at Ryde will function as a control for the Sacramento CWT release and represent fish not exposed to the interior Delta or Steamboat and Sutter Sloughs. The Port Chicago release is a control for fish not exposed to the Delta and can be used to estimate the probability of capture of the upstream groups at Chipps Island and verify that it is similar between releases.

The tags used for this experiment are decimal coded wire tags (CWT) and Vemco VL1 ultrasonic tags. The CWT's are 0.25 mm x 1.1 mm. whereas the Vemco VL1 ultrasonic tags are 1.4 grams, 17.5 mm in length and have a 44 day battery life. Ultrasonic tags will be turned on for 1 hour after tagging, turned off for 5 days (for recovery from surgery) and turned back on for the remaining 44 days. CWT tagging will be done at Coleman National Fish Hatchery. The CWT's are inserted into the juvenile salmon's snout and their adipose fin is clipped. VEMCO ultrasonic tags will be surgically implanted at Coleman by NOAA staff in late November and early January. All ultrasonically tagged fish will also have a CWT to reduce the time the ultrasonic fish need to be held separately at the hatchery prior to release. CWT'ing is done several weeks before fish are released. Both CWT (70,000) and ultrasonic tags (72) will be released at Sacramento on December 4, 2006 (DCC gates open) and on January 9, 2007 (DCC gates closed). Groups will be released in four discrete groups over a 24 hour period; day/ebb, day/flood, night/ebb and night/flood to obtain an average condition over the tidal cycle. USGS will model conditions and provide us with the optimal times of release depending on the tides. Fish will be held in net pens from the time of arrival at the site until they are released on the correct tidal cycle. The four groups of coded wire tagged fish will be brought to the release site in two trips with two trucks each on December 4 and January 9th. One coded wire tag lot will be released with each group of ultrasonic tagged fish at Sacramento over the four discrete periods.

Other CWT groups will be released at Ryde (37,500) on December 8 and January 12 and Port Chicago (12,500) on December 11 and January 16. Three tag lots will be used for each Ryde release and 1 tag lot will be used for each Port Chicago release.

CWT's will be recovered at Chipps Island in a mid-water trawl towed behind a 39'boat. Sampling will be conducted daily for three weeks after each release. Ten, 20 minute tows will be conducted each sampling day. Juvenile salmon caught with adipose fin clips (coded wire tagged) are returned to the lab for dissection and decoding. CWT's will also be recovered in future years in the ocean fishery with recovery information reported on the Regional Mark Processing Center website (www.rmpc.org).

CWT’s are read by dissecting out the tag, reading the numbers on the tag and entering it into a database. VEMCO ultrasonic tags are detected as the tagged fish migrate past fixed station VEMCO receivers located at various locations in the Delta (Figure 1). Data is electronically downloaded from receivers and summarized.

CWT survival between Sacramento and Ryde will be estimated by dividing the recovery rate at Chipps Island of the Sacramento group by that of the Ryde group. As the ocean recoveries become available in future years, they will be added to those recoveries made at Chipps Island to refine and lessen the variance of point estimates of the ratio. Russ Perry, a CALFED Fellow, will develop a model fom the ultrasonic data to estimate distribution and survival probabilities.

The results of this work will be used to design a full scale ultrasonic tagging experiment in the Delta. Using independent methodologies and comparing results will allow us to determine the best way to estimate survival in the future.

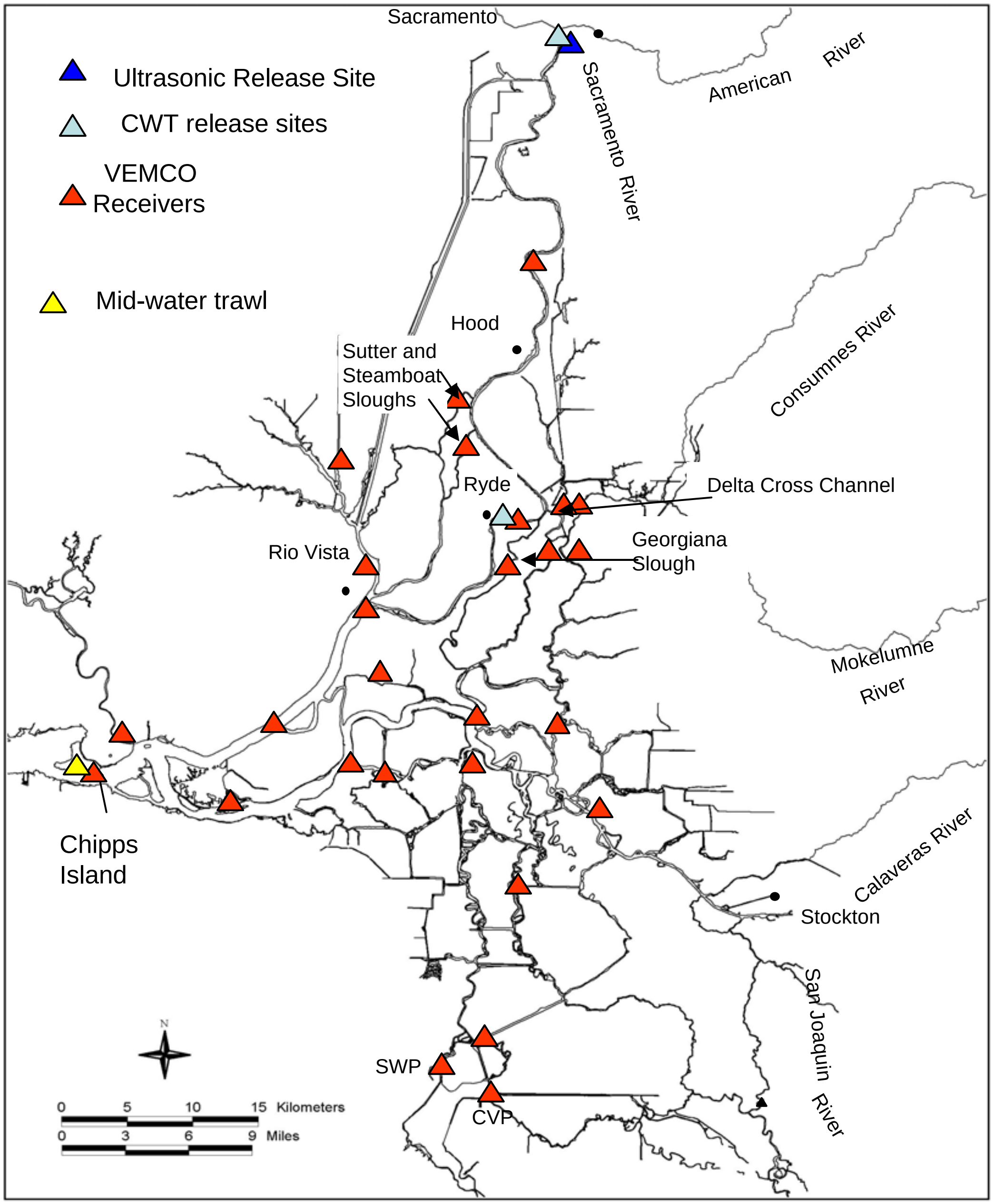


Figure 1: Detailed map of the Sacramento-San Joaquin Delta showing proposed release sites and locations of ultrasonic receivers, the Chipps Island trawl and the Delta Cross Channel.

Appendix C

Currently under production

Appendix D

2006 VAMP Study Proposal to Monitor the Migration of Juvenile Chinook Salmon Using Acoustic Telemetry

Dave Vogel
Natural Resource Scientists, Inc.

2006 VAMP Pilot Study to Monitor the Migration of Juvenile Chinook Salmon Using Acoustic Telemetry

Dave Vogel
Natural Resource Scientists, Inc.

Introduction

During the 2006 Vernalis Adaptive Management Program (VAMP), a pilot study was initiated to monitor the migration of juvenile Chinook salmon using acoustic telemetry. The study was prompted by interest from VAMP participants to determine if the applied technology would provide detailed information about the movements of juvenile salmon through the Delta. In particular, there was need to evaluate how lack of a barrier at the Old River/San Joaquin River flow split may affect juvenile salmon and determine migration pathways used by salmon at other locations further downstream in the San Joaquin River. The project was conducted as a short-term, small-scale pilot effort to evaluate if the equipment, techniques, and results would be valuable toward supplementing existing VAMP studies in future years. The following section provides a brief description of the results of the 2006 pilot study. Additional details will be provided in a separate technical report.

Summary of 2006 Pilot Study

The pilot study was conducted from May 8 through May 19, 2006, during high flow conditions. One hundred Merced Hatchery juvenile fall-run Chinook were used for the study. A request was made to the California Department of Fish and Game to include wild fish captured in the Merced River but was not approved. Miniature acoustic transmitters (0.8 grams) (Figure 1) were surgically implanted (Figure 2) inside the hatchery fish. Each transmitter was programmed to be individually identifiable based on sound transmission pulse width and repetition rate.

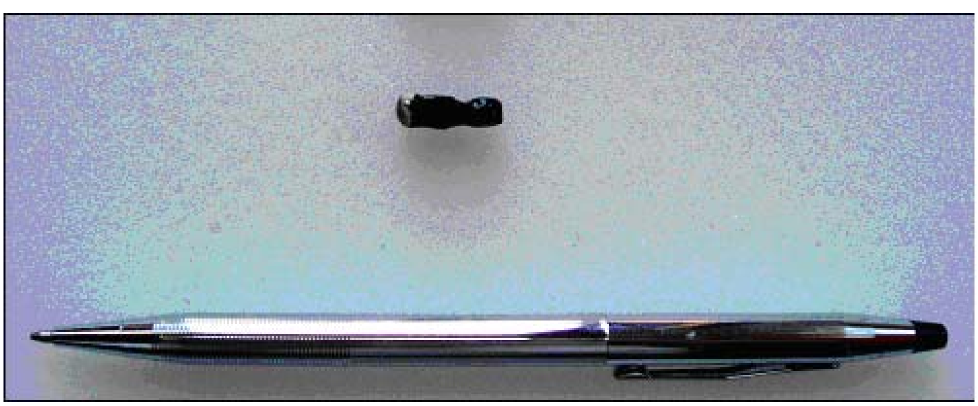


Figure 1. An acoustic transmitter.

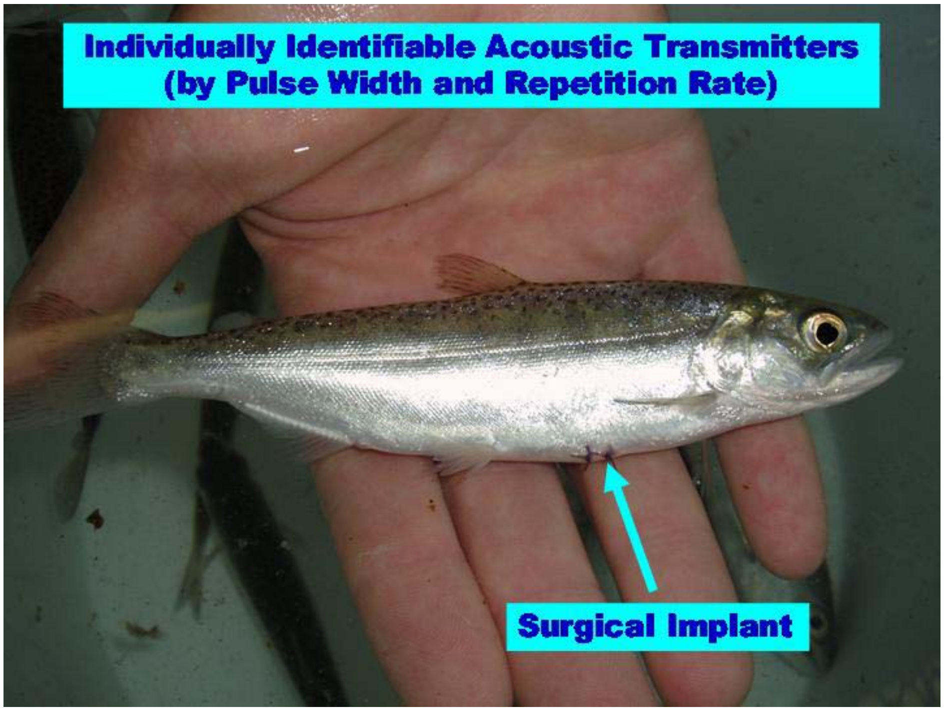


Figure 2. A juvenile Chinook salmon with a surgically implanted acoustic tag.

Acoustic receivers (Figure 3) capable of recording each acoustic-tagged salmon were deployed off the levee banks (Figure 4) or from California Department of Water Resources tide gauging stations to detect fish passing each site. The receivers electronically record the time when each fish is detected.

Figure 3. An acoustic (hydrophone) receiver, connection cable, output extender box, and 12-VDC marine battery.

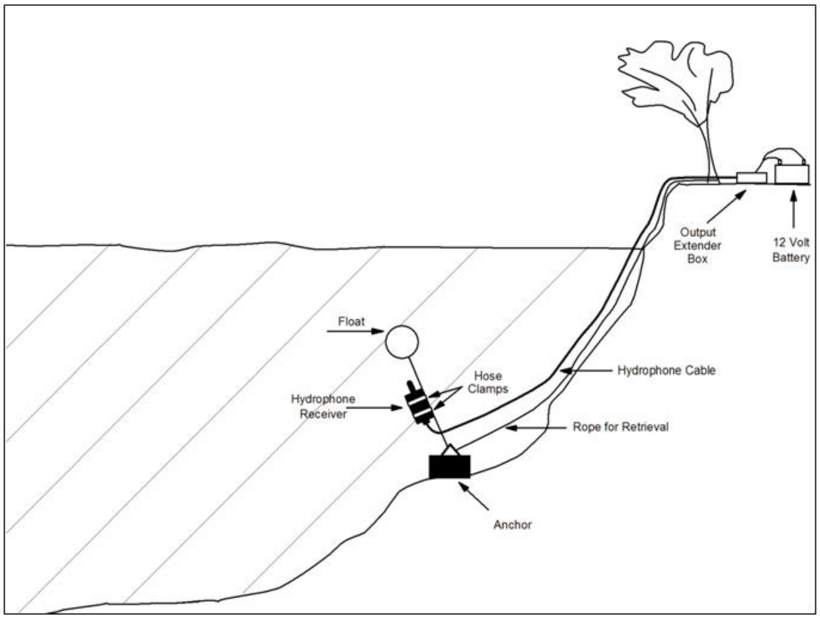


Figure 4. Deployment of an acoustic receiver from a Delta levee.

The acoustic-tagged salmon were released at two locations in the lower San Joaquin and monitored with acoustic receivers placed at five locations shown in Figure 5.

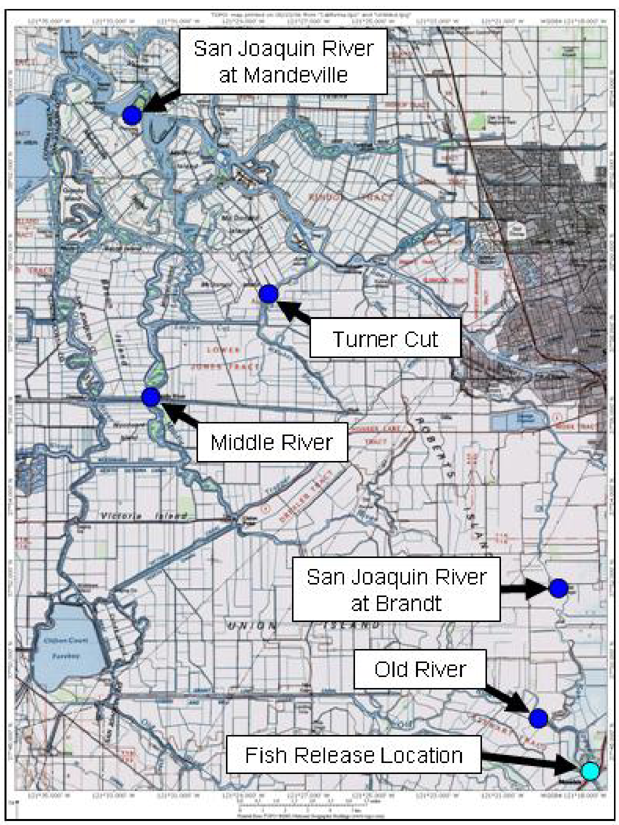


Figure 5. Release locations of acoustic-tagged juvenile salmon and deployment locations of acoustic receivers during May 2006.

Only five acoustic receivers were available for this pilot study and, therefore, data collection was limited by coverage in only several Delta channels where fish may migrate. Other important areas could not be included in the study (e.g., south Delta export facilities).

An initial release of 34 acoustic-tagged salmon was made at Mossdale on May 8, 2006. Originally, it was planned to release 100 fish on that date, but the remaining fish at the hatchery were slightly smaller than required for tag implantation. Therefore, the remaining fish were kept at the hatchery to acquire additional growth for tagging, then subsequently released on May 15, 2006.

First Fish Release (May 8, 2006)

Of the 32 fish released at Mossdale on May 8, 2006, 25 fish (78%) were detected to have been diverted into Old River and 5 fish (16%) were detected to have migrated down the lower San Joaquin past the Brandt gauge. The fate of the remaining 2 fish is unknown, but, given the caveats described below, the fish were presumed to have been preyed upon because the transmitters were not detected at any receivers during the study period.

Table 1. Acoustic tag detections following a release of 32 fish at Mossdale on May 8, 2006

# Detected in Old River	# Detected in San Joaquin River at Brandt Gauge	# Assumed Lost Due to Predation
25* (78%)	5 (16%)	2 (6%)

* Three of these fish were subsequently detected in Middle River

The proportionally high rate of fish diverted into Old River could not be explained by proportion of flow diverted. Based on preliminary flow data, Old River was diverting approximately 53% of the mainstem San Joaquin flow at the time the fish approached the flow split, but at least 78% of the fish were diverted into Old River.

Second Fish Release (May 15, 2006)

Because such an unexpectedly high proportion of the fish were diverted into Old River during the first fish release, the second release was modified by releasing 35 fish at Mossdale and 33 fish at Dos Reis on May 15, 2006. Based on preliminary flow data, approximately 51% of the mainstem San Joaquin flow was diverted into Old River at the time fish approached the flow split, but the majority of fish released at Mossdale entered Old River (Table 2). Of the 33 fish release at Dos Reis, only 14 (42%) passed the first downstream receiver at the Brandt gauge (Table 3). The fate of the remaining 19 fish (58%) is unknown but the fish were assumed to be consumed by predators because the transmitters were not detected by any fixed-station receiver during the study period.

Table 2. Acoustic tag detections following a release of 35 fish at Mossdale on May 15, 2006		
# Detected in Old River	# Detected in San Joaquin River at Brandt Gauge	# Assumed Lost Due to Predation
14 * (40%)	11 (31%)	10 (29%)
* One of these fish was subsequently detected in Middle River and two of these fish were subsequently detected by mobile telemetry and assumed preyed upon.		

Table 3. Acoustic tag detections following a release of 33 fish at Dos Reis on May 15, 2006	
# Detected in San Joaquin River at Brandt Gauge	# Assumed Lost Due to Predation
14 (42%)	19 (58%)

No fish were detected in Turner Cut or the lower San Joaquin River at Mandeville Island. The Turner Cut acoustic receiver had complete coverage of the cross-section of the river channel so no acoustic-tagged fish passing the site could have escaped detection. The Mandeville Island receiver had coverage of the majority of flow passing the site. Some flow passing around a side channel at the site could not be covered by the receiver and, therefore, it is possible some fish may have escaped detection. However, that circumstance is probably not likely based on fish behavior derived from extensive fish radio-telemetry in that region during prior studies. If those fish passing the Brandt gauge receiver took a long time (e.g., a week) to reach Turner Cut or Mandeville Island, it is also possible that the transmitter battery could have died. However, based on past radio-telemetry studies on juvenile salmon in that region, fish movements past the area would be expected to be only several days.

Because of the limited number of acoustic receivers available for this pilot study, no data could be collected upstream of the two fish release sites. Therefore, it is possible (but not probable) that some acoustic-tagged salmon could have swam upstream during the period of study. It is more likely that some salmon were consumed by predatory fish that swam upstream escaping detection from any receiver. Notably, May is the peak upstream migration period for striped bass spawning.

The fate of fish after diversion into Old River could not be determined from this study due to the limited number of acoustic receivers. However, four of the fish diverted into Old River were subsequently detected in Middle River near Bacon Island. Because of the small amount of flow diverted at the Old River/Middle River flow split, it is likely those fish moved west via Grant Line Canal or Fabian and Bell Canal, then north (past the south Delta export facilities) and subsequently moved across to Middle River through one of several interior Delta channels (e.g., Victoria Canal, Woodward Canal). A prior radio-telemetry study on juvenile salmon in this region demonstrated such migration pathways north of the export facilities.

On May 19, 2006, all five receivers were removed from Delta channels. One receiver was utilized as a “mobile” receiver in an attempt to locate transmitters that were not detected at either the Old River or lower San Joaquin River (Brandt) receiver sites. This was accomplished by hanging the receiver submerged off a boat and drifting the distance from just upstream of the Mossdale bridges to downstream of the location where the lower San Joaquin receiver had been deployed at the Brandt gauge. During this final mobile survey, 13 acoustic transmitters were located within the surveyed reach. Five transmitters were detected in a large, deep hole in the San Joaquin River adjacent to the Old River flow split (Figure 6). At that location, numerous striped bass were observed feeding. Eight additional transmitters were located further downstream near pump station structures in the river channel. All of these transmitters were assumed to have been defecated from predatory fish that had consumed acoustic-tagged juvenile salmon, although this could not be confirmed.

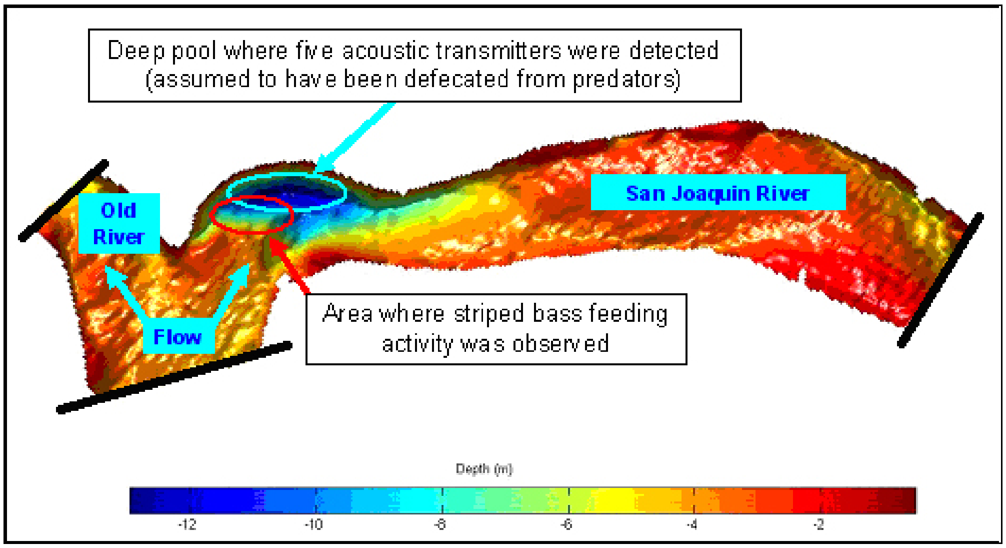


Figure 6. Plan-view bathymetry of the Old River/San Joaquin River flow split (bathymetry graphic courtesy of Jon Burau and Aaron Blake, USGS).

Conclusions from the 2006 Pilot Study

- The equipment and techniques worked well, but the study was limited by the number of available acoustic receivers; additional receivers deployed at other locations throughout the Delta would maximize collection of data useful to determine the fate of salmon migrating through the Delta.
- A higher than anticipated number of fish were diverted into Old River; the proportion of fish diverted into Old River was higher than the proportion of flow diverted.
- Study results suggested a high rate of predation; future use of a mobile receiver would locate areas of predation.